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An operative lagrangian model for simulating radioactivity dispersion in the Strait of Gibraltar

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Abstract

GISPART (GIbraltar Strait PARticle Tracking model) is a three-dimensional particle tracking code to simulate the dispersion of radionuclides in the Strait of Gibraltar. It consists of a hydrodynamic module that is run off-line to determine tidal constants and residuals in the domain. This information is stored in several files that are read by the dispersion module to reconstruct water movements. The dispersion module uses a lagrangian approach. Thus, a radionuclide release is simulated by a number of particles, whose paths are computed individually. Radionuclide concentrations are obtained from the density of particles per water volume unit. Some examples of results are shown. The model is also available on-line.

Keywords: Strait of Gibraltar; Radioactivity; Dispersion; Numerical modeling; Particle tracking

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1. Introduction

The Strait of Gibraltar, connecting the Atlantic Ocean and the Mediterranean Sea, has a high ecological value. Indeed, the Natural Park of the Strait was created in 2003, which includes a marine and a terrestrial part. Over 1900 marine species of flora and fauna have been described, many of them under strict protection due to their endemic character and/or rareness. Also, the Strait is essential in marine and aerial migratory processes. Fishing activities must be added as well. Finally, the coasts of the Strait have a high tourist interest, that leads to a high density of population during the summer season.

As the only connection between the Atlantic and the Mediterranean, intense shipping activities take place with traffic of over 70 000 ships per year and 30% of them declaring hazardous cargos. In particular, shipping activities include the transit of nuclear submarines and transport of radioactive materials. It is usual to find adverse meteorological conditions in the Strait (poor visibility, persistent fog conditions and strong winds) that make navigation difficult. As a consequence, it is relevant to have an operative radionuclide dispersion model that could be used in the assessment of contamination after an accident in the Strait. Such a model, denoted GISPART (GIbraltar Strait PARticle Tracking model), is now available at www.personal.us.es/rperianez. The objective of this note consists of providing a brief description of this model and some examples of the kind of results that may be obtained.

2. The model

The GISPART model consists of two sub-models [full details may be seen in Periáñez (2004b)]. First, a hydrodynamic model is run off-line. This provides tidal constants and residuals that are used by the dispersion sub-model to determine the instantaneous water current at any position in the Strait and any instant of time.

A 2D depth averaged hydrodynamic model was used since tidal flow in the Strait can be considered as barotropic (Tsimplis and Bryden, 2000). Indeed, these authors found that tidal currents are larger than the mean inflow or outflow, obscuring the expected two-layer character of the mean flow. Thus, 2D depth averaged models have been applied before to describe tides in this area (Tejedor et al., 1999). It is also known that the surface manifestation of baroclinic tidal currents is usually small. Nevertheless, pollutants considered in this work are released at the sea surface and remain close to the surface after the typical simulated times (several days). Thus, the use of a 2D depth averaged barotropic model to obtain surface currents is justified.

The barotropic hydrodynamic equations were solved over the model domain using finite differences. Surface elevations were prescribed from observations along open boundaries and radiation conditions were used to determine the current component that is normal to the open boundary. A quadratic law for bottom friction was applied. The computational grid used to solve the equations is shown in Fig. 1. Horizontal resolution is $\Delta x = \Delta y = 2500$ m. Time step was limited to 5 s due to the CFL (Courant-Friedrichs-Lewy) stability condition. The hydrodynamic model was

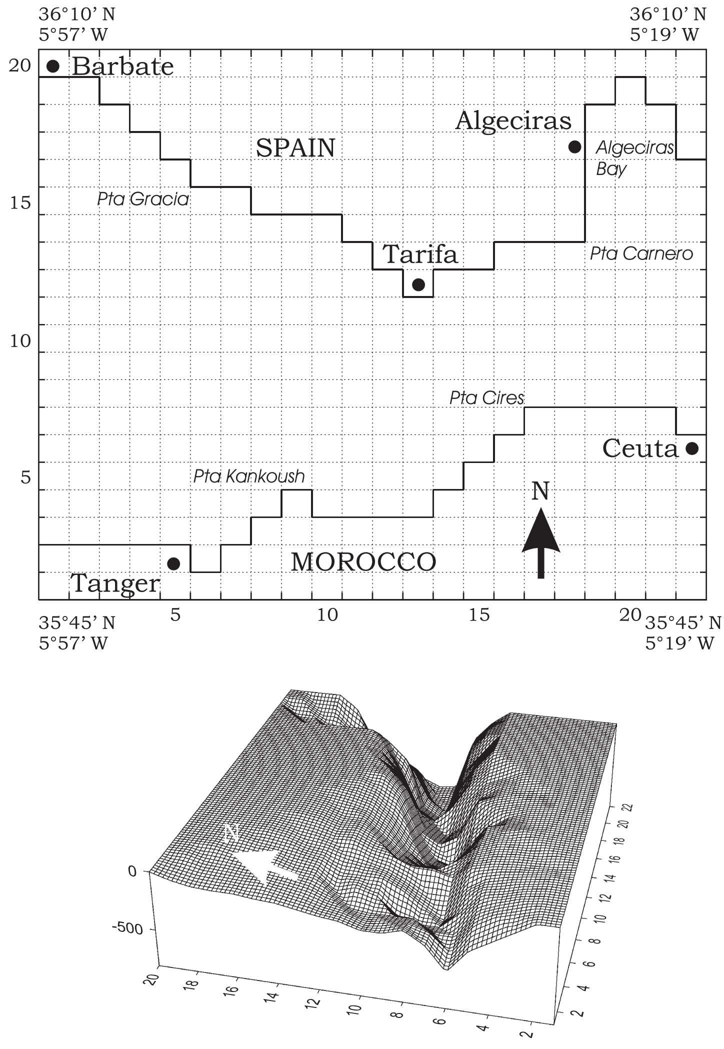

Fig. 1. Computational grid showing some important towns (circles) and locations referred in Table 1. Each unit in the x and y axis is the grid cell number (thus equal to 2500 m). The topography of the Strait is also shown. Units in the vertical axis are in metres.

run until a cyclic stable solution was achieved. Then standard tidal analysis was carried out (Pugh, 1987, Chapter 4) to determine tidal constants, and tidal residual transport was evaluated as well. These calculations were carried out separately for the two main tidal constituents, M_2 and S_2. Results of the hydrodynamic model have been validated through comparisons of observed and computed values of tide amplitude and phases and current ellipse parameters for 16 points in the domain. As an example, computed tide amplitudes and phases for several points indicated in Fig. 1 were compared with the corresponding measured values in Table 1. Generally,

Table 1
Observed and computed amplitudes (cm) and phases (deg) of tidal elevations at several points in the Strait (Periáñez, 2004b)

Station	M_2				S_2			
	A_{obs}	g_{obs}	A_{comp}	g_{comp}	A_{obs}	g_{obs}	A_{comp}	g_{comp}
Pta Gracia	64.9	49	70.5	57	22.3	74	24.8	81
Pta Kankoush	51.8	69	52.7	59	20.1	90	18.9	86
Tarifa	41.5	57	46.2	52	14.2	85	17.4	77
Pta Cires	36.4	47	38.5	56	14.1	74	14.3	82
Algeciras	31.0	48	25.0	48	11.1	74	10.0	71
Pta Carnero	31.1	48	25.6	46	11.5	71	10.4	69
Ceuta	29.7	50	25.0	50	11.4	76	10.0	72

there is a good agreement between measurements and calculations. More details may be seen, however, in Periáñez (2004b).

The dispersion model used a 3D particle tracking method. The model may deal with both instantaneous and continuous releases of dissolved radionuclides at the sea surface, which were simulated by a discrete number of particles. Each particle was equivalent to a number of units (for instance Bq). At the end of the simulation, the density of particles per water volume unit was calculated to obtain the radionuclide concentration. While there is no stability criterion equivalent to the CFL condition in the particle tracking calculations, it is wise to ensure that each particle does not move through a distance that exceeds the grid spacing during each time step. This was satisfied using $\Delta t = 600$ s. Horizontal and vertical diffusivities are 1.7 and 0.001 m^2/s, respectively.

The adsorption of radionuclides by suspended particles is neglected due to the extremely low suspended sediment concentrations in the Strait (León-Vintró et al., 1999). However, adsorption–desorption reactions can be described in terms of kinetic rates and solved using a stochastic method as in Periáñez and Elliott (2002).

Although the dispersion model is 3D, the hydrodynamic model provides depth averaged currents. Thus, a standard current profile (Pugh, 1987; Riddle, 1998) was generated by the dispersion code from the depth averaged current to compute advection at each particle depth. The effect of wind was included as usual in particle tracking models. Thus, it was assumed that the water surface moves in the direction of wind at a speed equal to 3% of the wind speed 10 m above the sea surface. This current decreased logarithmically to zero at a depth usually taken as 20 m (Pugh, 1987; Proctor et al., 1994). Radioactive decay was computed using a stochastic method, as well as turbulent diffusion (Proctor et al., 1994; Periáñez and Elliott, 2002).

Date and time of the discharge (and duration in the case of continuous releases) must be specified since the fate of the release will depend on the tidal state when it took place. Thus, the appropriate phase of each tidal constituent at $t = 0$ must be specified. The values used in this model corresponded to the origin of time being January 1, 2003 at 0:15 h Greenwich time. Wind conditions must also be specified. Detailed information on required input data, installation and output may be seen in the model instructions (Periáñez, 2004a), available on-line. Technical details on model equations and numerical solution may be seen in Periáñez (2004b).

3. Examples of results

As an example, an arbitrary continuous release (25 particles were introduced each time step, thus the final particle number was 7200) of a long-live radionuclide was introduced during two days in front of Tarifa, at the surface, under calm conditions. The total activity released was fixed as 1 TBq. Release started on October 19, 2004, at 0:00 h UTC as an example. A map showing the position of particles after 36 h and the corresponding concentrations at the surface after 48 h is presented in Fig. 2. There was a net transport towards the Mediterranean Sea due to the residual currents, although the patch moved forward and backward in the Strait following tidal oscillations. Maximum concentrations that would be detected after 2 days are about 70 Bq/m^3. Of course, computed concentrations correspond to average values over the mesh ($\Delta x \times \Delta y \times h$), where h is the maximum depth reached by particles. This depth is about 40 m for a two days simulation.

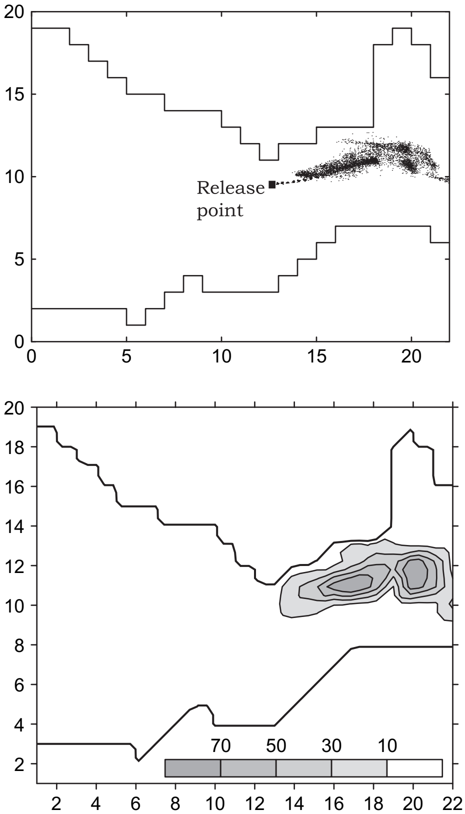

Fig. 2. Top: position of particles after 36 h of continuous release at cell (13, 10). Bottom: computed concentrations at the surface (Bq/m^3) after 48 h.

Exactly the same simulation was repeated but with a constant 25 m/s wind blowing from the east. East winds (known as *levantes*) are very common in the Strait, blowing an average of 165 days per year, predominantly from April to October. Average speed is of the order of 14 m/s, and maximum speed reaches 35 m/s. Gust of winds can remain up to 7–10 days. Results of the simulation are presented in Fig. 3. East winds are directed in the opposite direction than the surface residual current in the Strait (directed to the east). Thus, east winds tended to retain contaminants in the Strait and the patch size increased due to turbulent diffusion. This can be clearly seen if Figs. 2 and 3 are compared. Also, there was a higher impact on the Spanish coast, from Tarifa to Pta Carnero, if the release occurs during a levante event. In contrast, west winds (in the same direction as the residual current) produced a fast contaminant flush off from the Strait.

Other simulations have shown that if an accident was to occur in the Algeciras Bay (Algeciras is the most important port in Spain and number 25 in the world), the radioactive impact may be relevant since contaminants are retained into the Bay.

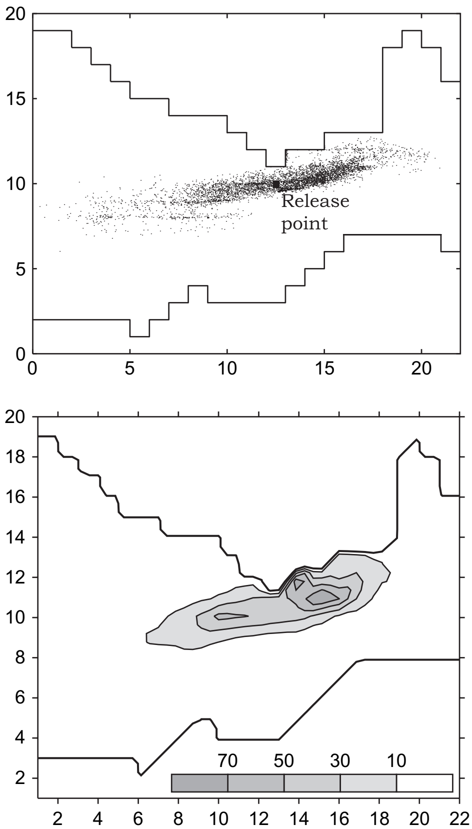

Fig. 3. As in Fig. 2 but with a 25 m/s wind blowing from east.

Only with a wind blowing from the north would a faster contaminant flush off from the Bay occur.

4. Conclusions

In summary, although only a couple of simulation examples are shown, it seems clear that the fate of a radionuclide release depended not only on the position of the source, but also on wind conditions and tidal state as well. Thus, a higher radioactive impact on the coast may be produced if the release occurs during a neap tide, since currents are weaker and radionuclides would remain in the Strait for a longer time. It is useful to have a mathematical tool that can be used to assess the fate of a radioactive discharge that could occur after an accident in the Strait at any position, time and for any meteorological conditions. More details on model output, as animations showing snap shots of particle positions during the simulation time, can be seen in Periáñez (2004b).

References

León-Vintró, L., Mitchell, P.I., Condren, O.M., Downes, A.B., Papucci, C., Delfanti, R., 1999. Vertical and horizontal fluxes of plutonium and americium in the western Mediterranean and the Strait of Gibraltar. The Science of the Total Environment 237, 77–91.

Periáñez, R., 2004a. GISPART model instructions Available on-line at. www.personal.us.es/rperianez.

Periáñez, R., 2004b. A particle-tracking model for simulating pollutant dispersion in the Strait of Gibraltar. Marine Pollution Bulletin 49, 613–623.

Periáñez, R., Elliott, A.J., 2002. A particle tracking method for simulating the dispersion of non-conservative radionuclides in coastal waters. Journal of Environmental Radioactivity 58, 13–33.

Proctor, R., Flather, R.A., Elliott, A.J., 1994. Modelling tides and surface drift in the Arabian Gulf: application to the Gulf oil spill. Continental Shelf Research 14, 531–545.

Pugh, D.T., 1987. Tides, Surges and Mean Sea Level. Wiley, Chichester.

Riddle, A.M., 1998. The specification of mixing in random walk models for dispersion in the sea. Continental Shelf Research 18, 441–456.

Tejedor, L., Izquierdo, A., Kagan, B.A., Sein, D.V., 1999. Simulation of the semidiurnal tides in the Strait of Gibraltar. Journal of Geophysical Research 104, 13541–13557.

Tsimplis, M.N., Bryden, H.L., 2000. Estimations of the transports through the Strait of Gibraltar. Deep Sea Research 47, 2219–2242.